

INTRODUCTION

We are surrounded by technology and innovation. Electricity is one of the greatest innovations of mankind. It has now become a part of our daily life and one cannot think of a world without electricity. Electricity is now an important part of homes and industries.

Almost all the devices at homes, businesses and industries are running because of electricity (Fig. 1.1). The primary use of electricity depends on the place where it is used and the nature of the facility. You have seen bulbs, tubelights, fans, fridges, TVs and electronic gadgets at your home. All these run on electricity. At present electricity plays a vital role in our day-to-day life and in the country's economy.

Any country's development is measured by the per-person-consumption of electricity. Presently, everything in human life is dependent upon electricity whether it is in the health, transport, agriculture or industrial sectors.

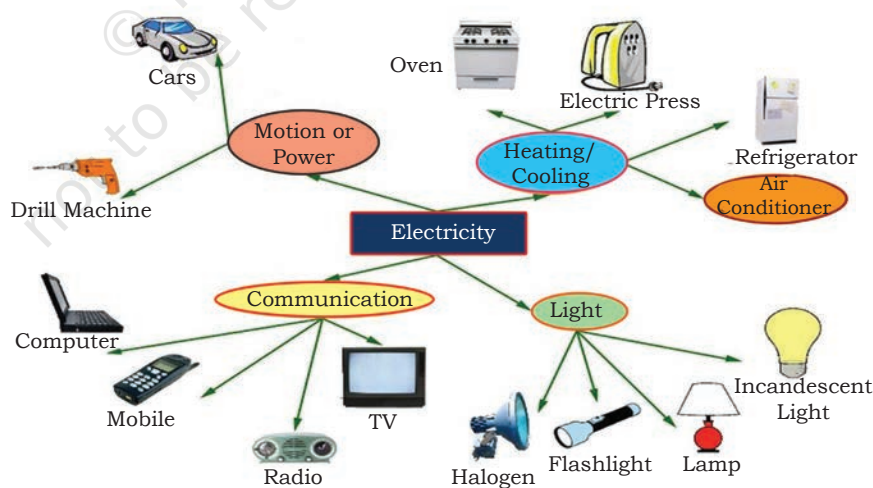


Fig. 1.1 Uses of electricity

SESSION 1: ELECTRICITY GENERATION CONCEPT

Origin of Electricity

Electricity is one of the most commonly used forms of energy. The term electricity comes from the Greek word *elektron* which means amber. It is converted from mechanical to electrical energy with the help of a prime mover i.e., from turbine to generator. Many people give credit to Benjamin Franklin for discovering electricity, but his experiments only helped to establish the connection between lightning and electricity.

Basic Concept of Electricity

Electricity is a type of energy which involves the flow of electrons. All elements are made up of atoms. The centre of an atom is called the nucleus. The nucleus has positively charged particles known as protons and electrically neutral particles called neutrons. The nucleus of an atom is surrounded by negatively charged particles known as electrons (Fig.1.2). The negative charge of an electron is the same as the positive charge of a proton, and the number of electrons in an atom is equal to the number of protons.

Distribution of Electrons in the Orbits of Copper Atom

From the generating station electricity arrives at homes through wires. Electric lamps, electric heaters, fans, computers, etc., use electricity to work. Many appliances at home such as washing machines and electric cookers use electricity. In factories, electricity is used to run machines. People who deal with electricity and electrical devices are called Electricians.

There are two types of electric charges—positive and negative. Similar charges repel each other and opposite charges attract. This means that if you put two negative charges close together and let them go, they will move apart. This is also true for two positive charges. But if you put a positive charge and a negative charge close together, they will attract each other.

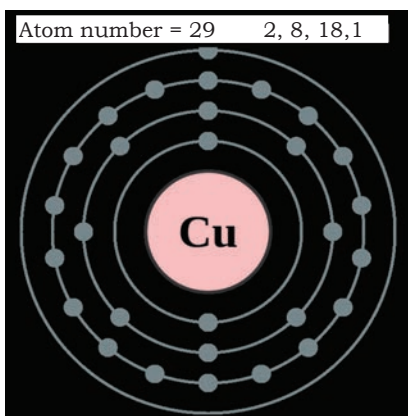


Fig. 1.2 Electrons



Importance of Electricity

Electricity makes it possible to light our homes, roads, offices, markets and factories. This helps us to continue work during night hours. A power station provides us electricity. If the electricity supply fails, electrical torches are used for light. We use electricity to operate the pump that lifts water from wells or ground level to rooftop water tank. We need electricity to run computers in shops, offices, banks and other establishments. Other electrical equipment like AC, geyser, electrical iron, television, refrigerator, induction cooker, oven, etc., require electricity to run them.



Fig. 1.3 Electricity used for lighting



Fig. 1.4 Electricity used for heating

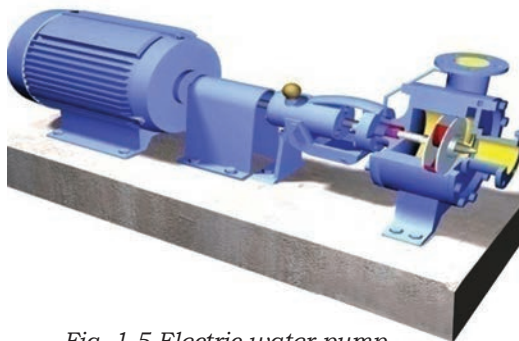
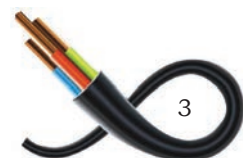


Fig. 1.5 Electric water pump

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Generation of Electricity

The basic principle of electrical generator is Faraday's Law of electromagnetic induction. An electrical generator (Fig. 1.6) is used to convert mechanical energy into electrical energy. Generation of electrical energy is conversion of kinetic energy into electrical energy.

Experiment of Michael Faraday

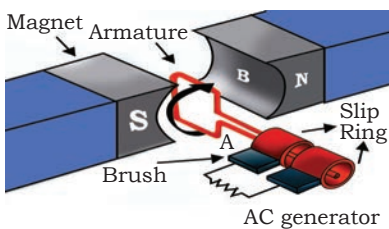


Fig. 1.6 Diagram of electromagnetic generator

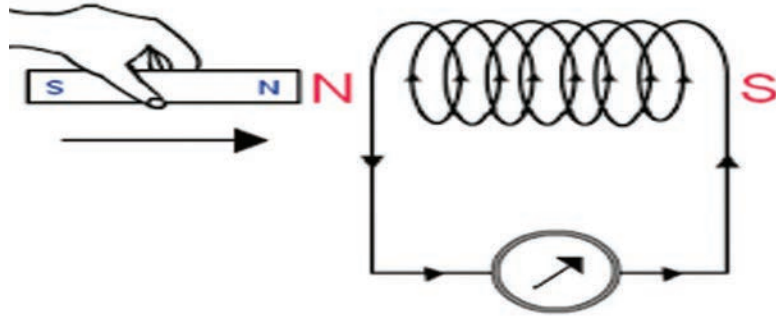


Fig. 1.7 Experiment of Michael Faraday

Electromagnetic induction is the production of an electromotive force across a conductor, when it is exposed to a varying magnetic field. It is described by Faraday's Law of Electromagnetic Induction (Fig. 1.7).

Electricity Generated by Electrochemical Cell

An electrochemical cell is a device which is capable of generating electrical energy through chemical reactions. A common example of an electrochemical cell (Fig. 1.8) is a standard 1.5 V cell meant for consumer use.



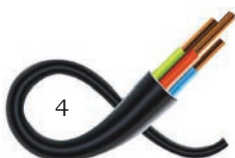
Fig. 1.8 Electrochemical battery



Fig. 1.9 Electricity generated by solar panel

Electricity Generated by Solar Cell

A solar cell (Fig. 1.9) is a device that converts light energy into electrical energy. This conversion is called the photovoltaic effect. Solar cells have many applications. They have been used in situations where electrical power is unavailable, such as in remote areas, earth-orbiting satellites and space probes, consumer systems like handheld calculators or wrist watches.



Electricity Generated by Thermal Power Station

A thermal power station (Fig.1.10) is a power station in which heat energy is converted to electrical energy. In most of the places in the world the turbine is steam-driven. Water is heated, which turns into steam and spins a steam turbine which drives an electrical generator. In a thermal power station fuel, such as coal, oil or gas is burned in a furnace to produce heat-chemical to heat energy. This heat is used to change water into steam in the boiler and this drives the generator to produce electricity by converting mechanical to electrical energy.

Generation and Transmission of Electricity

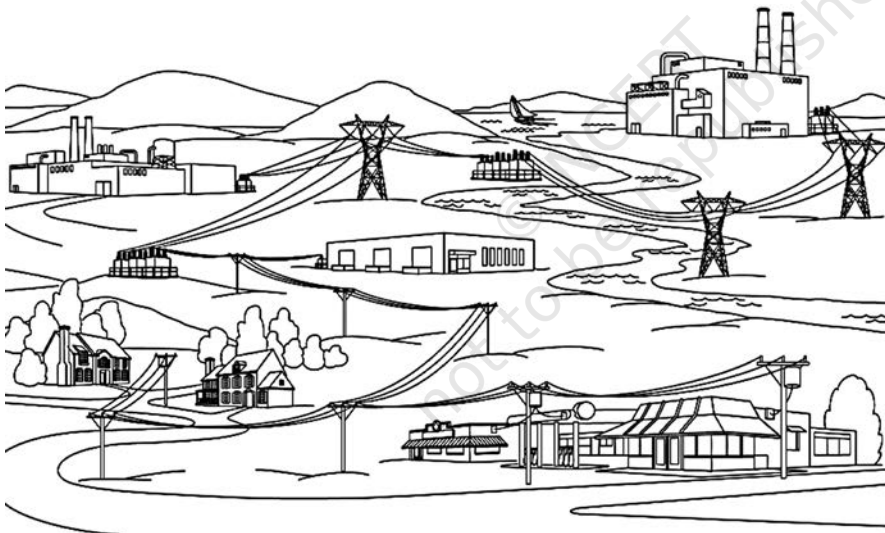
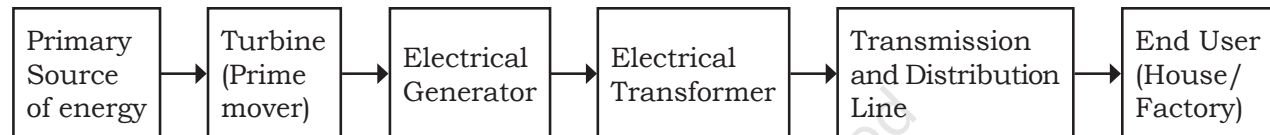
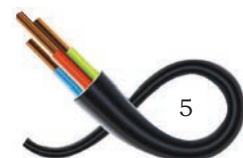


Fig. 1.10 Power Station

Our day starts and ends with the use of various electrical devices. Some of them are LED lights, fan, AC, refrigerator, motor, etc. The source where electricity is generated is far away from residential areas. This place is known as a power station. A power station (Fig. 1.10)



NOTES

is also known as a power plant or powerhouse. Power station may contain one or more electric generators. Generator converts the mechanical power into electrical power. Most power stations in the world burn fossil fuels like coal, oil and natural gas to generate electricity. But there is an increasing use of cleaner renewable sources, such as solar, wind, wave and hydroelectric energy.

Status of Electricity Production in India

1. Total Installed Capacity (As on 30.06.2017)

Fuel	MW	% of Total
Total Thermal	2,20,576	67.0%
Coal	1,94,553	59.1%
Gas	25,185	7.6%
Oil	838	0.3%
Hydro	44,614	13.6%
Nuclear	6,780	2.1%
Renewable Energy Sources*	57,260	17.4%
Total	329,231	100%

Source: Central Electricity Authority (CEA)

*Installed capacity with respect to Renewable Energy Sources as on 31.03.2017.

Renewable Energy sources include small hydro project, gas produced from biomass power, urban and industrial waste power, solar and wind energy.

Practical Exercise

Activity 1

Make an electrical quiz board for list of source of electricity and their sharing percentage (%) in India

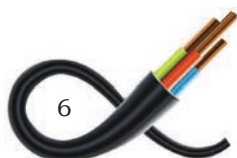
Objective

Students will be able to

1. identify the sources of electrical energy in India,
2. define their sharing percentage (%) and
3. make basic circuit connection.

Material required

One card-board (45 cm × 15 cm), insulated copper wire, one 9-volt bulb with holder, one 9-volt battery, 10-connectors with socket.

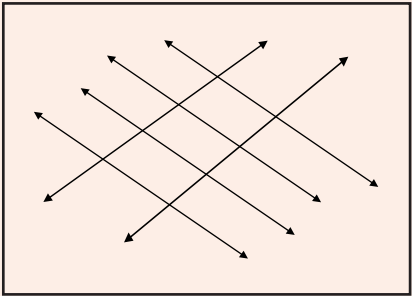


Tools and Equipment

S. No.	Particular	Specification	Quantity
1	Screw Driver	6"	01
2	Combination Plier	6"	01
3	Wire Stripper	--	01
4	Phase Tester	--	01

Coal	13.6
Gas	17.4
Oil	59.1
Hydro	7.6
Nuclear	0.3
Renewable	2.1

Front view of cardboard



Back view of cardboard

Fig.1 Electrical Cardboard

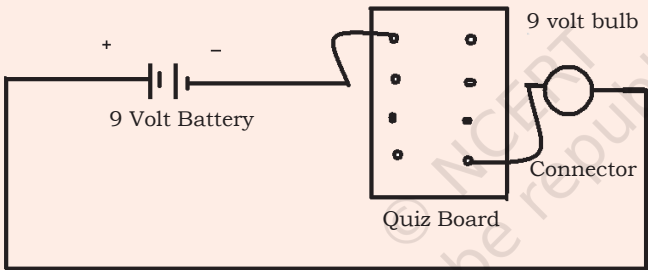


Fig.2 Electrical Circuit Diagram of Electrical Quiz Board

Procedure

1. Take one cardboard (45cm.x15cm.) and fix pieces of insulated wire with two metal connectors at the end of each wire.
2. Paste down name of energy source and percentage as shown in figure.
3. Connect each question to correct answer by a wire at the back of the cardboard.
4. Connect 9-volt battery and 9-volt bulb as shown in figure.
5. Clip one lead of connector to a question and clip the other lead to what you think is the correct answer.
6. If the answer selected by you is correct the bulb will glow because the connection wire on the back side of the board will complete the circuit.
7. If the answer is wrong, the bulb will not glow.

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Precautions

1. Every connection should be tight.
2. There should not be any wire left naked.
3. Question and answer should be connected correctly at the back side of the cardboard.

Check Your Progress

A. Fill in the blanks

1. The nucleus of an atom is surrounded by negatively charged particles known as _____.
2. Similar electric charges _____ each other and opposite charges _____ each other.
3. Benjamin Franklin's experiments helped in establishing the connection between _____ and _____.
4. Coal, oil or gas is used as a fuel in _____ power stations to convert heat energy into electrical energy.
5. Electromechanical cell is capable of generating electrical energy through _____.

B. Match the columns

1. Thermal power plant	(a) Renewable
2. Wind Power Plant	(b) Photovoltaic effect
3. Solar cell	(c) Water
4. Michael Faraday	(d) Law of Electromagnetic Induction

C. Multiple choice questions

1. Electricity was discovered by _____.
(a) Isaac Newton (b) Benjamin Franklin
(c) Max Plank (d) Rutherford
2. Which of these is the most commonly used source of energy for power generation in India?
(a) renewable (b) thermal
(c) nuclear (d) hydro
3. Which form of energy is converted by a solar cell into electrical energy?
(a) wind (b) thermal
(c) nuclear (d) light
4. Electricity is a type of energy which involves the flow of _____.
(a) protons (b) neutrons
(c) electrons (d) atoms



5. If you put two negative charges close together, they will _____.
- (a) attract
 - (b) repel
 - (c) not interact
 - (d) attract some time and repel some time.

D. Write short notes on

- 1. Use of thermal power plant
- 2. Generation of electricity
- 3. Different sources of energy

SESSION 2: BASIC UNITS AND DEFINITION OF ELECTRICITY

Electricity

Electricity is a form of energy which though cannot be seen but its effects can still be felt (Fig. 1.11).

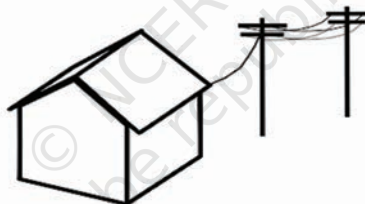


Fig. 1.11 Electricity as form of energy

Various Effects of Electric Current

(a) Heating effect: Heat is produced in a conductor, like nichrome, due to flow of current through it. It is called heating effect (Fig. 1.12) of electric current or Joule's law of heating. When electricity flows through a conductor like tungsten, light is emitted (Fig. 1.13) from the surface of conductor due to heating, such as in an electric bulb.



Fig. 1.13 Electric bulb



Fig. 1.12 Electric heater



ELECTRICITY

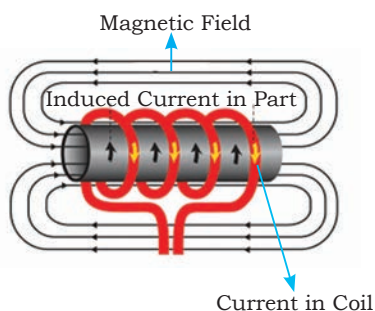


Fig. 1.14 Magnetic effect of electric current



Fig. 1.15 Physical effect of electricity on human body

(b) Chemical effect: When current is passed through an electrolyte, it breaks up in its ions. This is known as chemical effect of electric current.

(c) Magnetic effect: It was discovered by Faraday. A magnetic field (Fig. 1.14) is produced around the conductor through which current is flowing. This effect is called magnetic effect of electric current. When electricity flows through the human body contraction of nerves occurs, which can be fatal.

(d) Physical effect: When electricity flows through the human body, contraction of nerves takes place, which may be dangerous for a person's life. This is the physical effect of electric current (Fig. 1.15).

Voltage, Current, Resistance, Capacitance and Inductance

If we place two objects charged to different potential side by side, charge will not move from one object to the other. Now if the two are connected using a conductor, the flow of charge will take place. Charge will flow as long as there is a difference of potential between the two objects. The flow will stop as soon as their potential becomes equal. This flow of electric charge is called electric current.

The potential difference (PD) between two points is one volt, when the work done in moving one coulomb of charge between these points is one joule.

We know that flowing water constitutes water current. Similarly, if the electric charge flows through a conductor that means there is an electric current in the conductor. In a torch, the cells provide necessary potential difference for the flow of charges or an electric current through the torch bulb to glow. We have also seen that the torch gives light only when its switch is on. A continuous and closed path of an electric current is called electric circuit. Now, if the circuit is broken anywhere the current stops flowing. Electric current is expressed by the amount of charge flowing through a particular area in unit time. In other words, it is the rate of flow of electric charges.

Let us understand the analogy of water flow. Water will not flow by itself in a perfectly horizontal tube.



If one end of the tube is connected to a tank of water kept at a higher level, such that there is a pressure difference between the two ends of the tube, water will flow out of the other end of the tube.

Voltage plays an important role for flow of charges in a conducting wire. The electrons move only if there is a difference of electric pressure known as the potential difference or voltage. This difference of potential may be produced by a cell or a battery, consisting more than one electric cell. The chemical action within a cell generates the potential difference across the terminals of the cell. When the cell is connected to a conducting circuit element, the charge flows from one end to other.

Voltage

Voltage is the force required to make electricity flow through a conductor (Fig. 1.16). It is also called electric potential difference or electromotive force (EMF). Voltage may also be defined as the energy difference between the positive and negative terminals of a battery. This energy difference is measured in volts and represented by the symbol 'V' or 'E'.

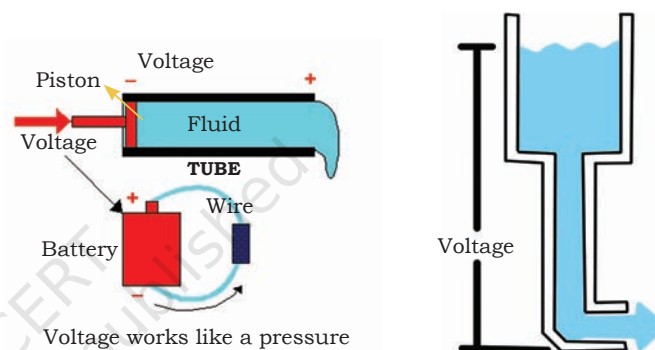


Fig. 1.16 Voltage

Current

Current is the flow of electrons in a material from one atom to the next atom in the same direction (Fig. 1.17). Just as pressure causes current to flow in a circuit, voltage causes current to flow in the conductor (Fig. 1.18). Current is measured in amperes and is denoted by the symbol 'I'.

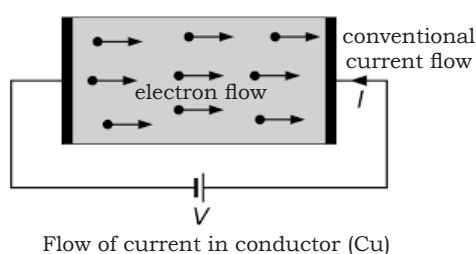


Fig. 1.17 Flow of electrons

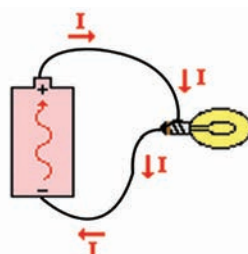


Fig. 1.18 Flow of current in conductor





Fig. 1.19 Electrical resistance

Resistance

The electrical resistance of an object is a measure of its opposition to the flow of electric current (Fig. 1.19). It is represented by the symbol 'R'. It is measured in ohms, symbolised by the Greek letter omega (Ω) by a measuring instrument called ohm meter.

Example: Some materials offer more resistance than others. Metals, such as silver, copper, aluminium and iron offer less resistance and are known as good conductors of electricity. On the other hand, materials like plastic, glass, mica and rubber offer high resistance and are called bad conductors of electricity, or good insulators.

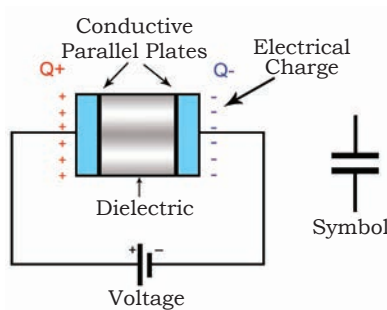


Fig. 1.20 Circuit diagram of a capacitor

Capacitance

Capacitance is a measure of a circuit's ability to store electrical charge (Fig. 1.20). Any object that can be electrically charged exhibits capacitance. If the charges on the plates are $+q$ and $-q$, respectively, and V is the voltage between the plates, then the capacitance 'C' is given by the formula:

$$C = q/V$$

A device manufactured to have a specific amount of capacitance is called capacitor (Fig. 1.21). A capacitor is made up of a pair of conductive plates separated by a thin layer of insulating material. Another name for the insulating material is dielectric material.

A common form of energy storage device is a parallel-plate capacitor. In a parallel plate capacitor, capacitance is directly proportional to the surface area of the conductor plates and inversely proportional to the distance between the plates.



Fig. 1.21 Capacitors

Inductance

Inductance is the property of an electric circuit that opposes any change in electric current. Resistance opposes current flow; inductance opposes changes in the current flow. Inductance is designated by the letter 'L'. The unit of measurement for inductance is Henry (H).



As Henry is a relatively large unit, inductance is often rated in millihenries or microhenries. Inductors are coils of wire wound for a specific inductance. The inductance of a coil is determined by the number of turns in the coil, the coil diameter and length, and the core material (Fig. 1.22).

Current flow produces a magnetic field in a conductor. The amount of current determines the strength of the magnetic field. As current flow increases, field strength increases and as current flow decreases, field strength decreases. Any change in current causes a corresponding change in the magnetic field surrounding the conductor.

Current is constant for a regulated direct current (DC) source, except when the circuit is turned on and off, or when there is a load change. However, alternating current (AC) is constantly changing, and inductance is continually opposing the change. A change in the magnetic field surrounding the conductor induces a voltage in the conductor. This self-induced voltage opposes the change in current. This is known as counter EMF.

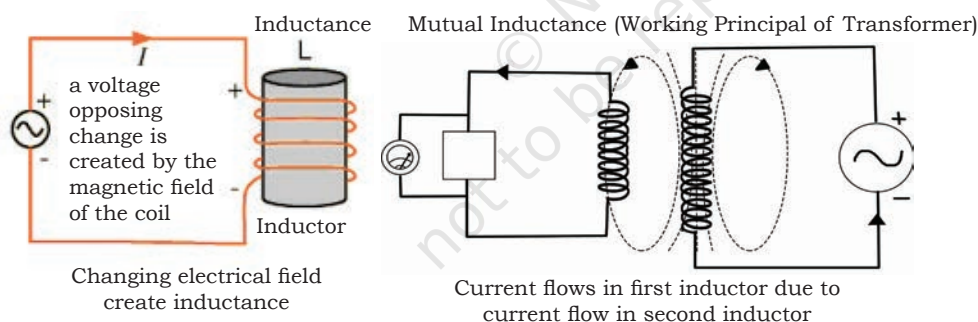


Fig. 1.22 Diagram showing how changes in electrical field create inductance

Electric Circuit

A simple electric circuit (Fig. 1.23) consists of a voltage source, some type of load and conductors to allow electrons to flow between the voltage source and the load. An electric circuit can be either in series or parallel.

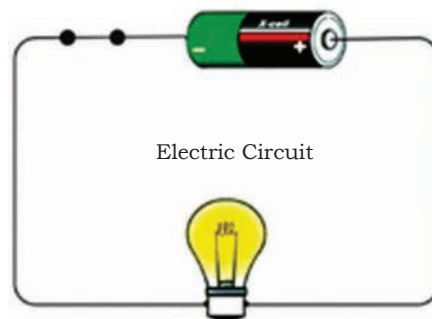
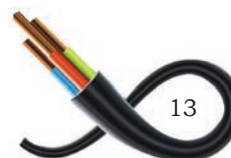


Fig. 1.23 Simple Electric Circuit



Understanding Series and Parallel Circuits

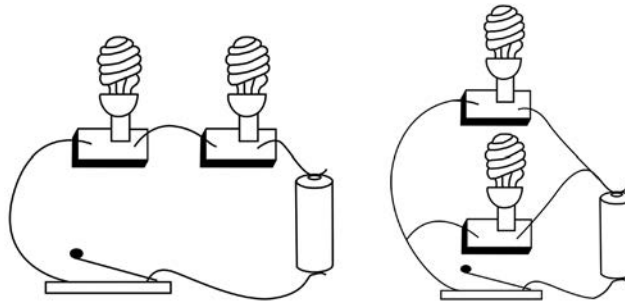


Fig. 1.24 Series and Parallel Circuit

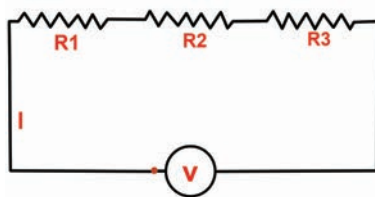


Fig. 1.25 Diagram of Series Circuit

Series Circuit

If two or more resistors (loads) are connected in such a way that they form a chain, one after the other, then each carries the same current when the combination is connected with the supply source. They are said to be connected in a series (Fig. 1.25).

This circuit is called series circuit.

In Series Circuit

Resultant Resistance (R) = $R_1 + R_2 + R_3$

Parallel Circuit

When two or more resistors (loads) are connected in such a way that each forms a separate path and carries a part of total current, they are said to be arranged in parallel and the circuit is called parallel circuit (Fig. 1.26).

In Parallel Circuit

Resultant Resistance $\left(\frac{1}{R_t}\right) = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$

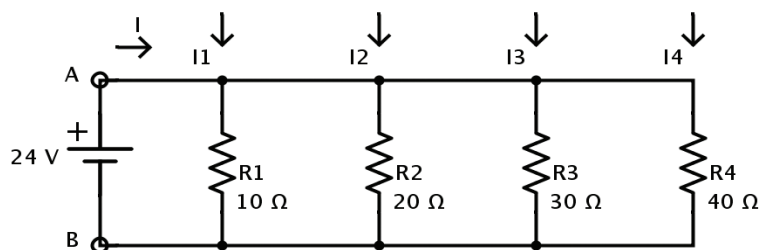


Fig. 1.26 Diagram of Parallel Circuit

Ohm's Law

Ohm's law describes the way current flows through a resistance when a different electric potential (voltage) is



applied at each end of the resistance. One way to think of this is as water flowing through a pipe. The voltage is like the water pressure, the current is the amount of water flowing through the pipe, and the resistance is the size of the pipe. The more the resistance, the less the current will flow through the electric circuit. Ohm's law shows that current varies directly with voltage and inversely with resistance.

Voltage is calculated by multiplying the current with the resistance, or

$$E = IR$$

This is called Ohm's law (Fig. 1.27). Ohm's law can be expressed in three ways:

$$E = IR \quad \text{or} \quad I = E/R \quad \text{or} \quad R = E/I$$

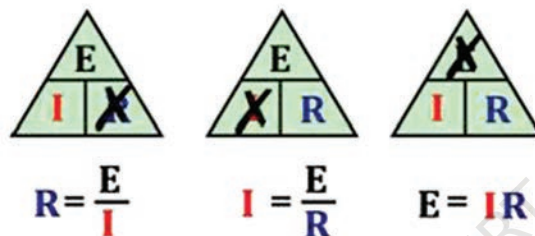


Fig. 1.27 Equation Triangles in Ohm's Law

Kirchhoff's Current Law

It states that the total current or charge entering a junction or node is exactly equal to the charge leaving the node, as no charge is lost within the node. In other words the algebraic sum of ALL the currents entering and leaving a node must be equal to zero I (current entering in the node) + I (current leaving the node) = 0.

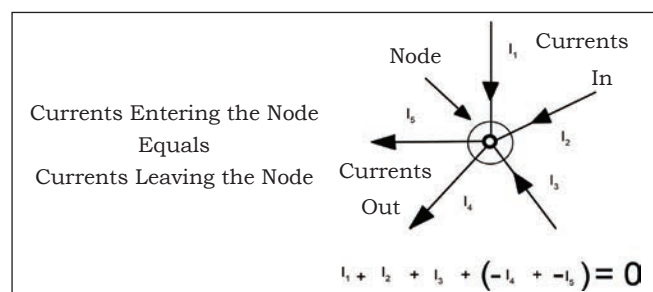


Fig. 1.28 Diagram of Kirchhoff's Current Law

This idea by Kirchhoff is commonly known as the Conservation of Charge or Kirchhoff's Current Law (KCL) (Fig. 1.28).

ELECTRICITY

NOTES



Here, the three currents entering in the node, I_1 , I_2 , I_3 are all positive in value and the two currents leaving the node, I_4 and I_5 are negative in value.

Then this means we can also rewrite the equation as:

$$I_1 + I_2 + I_3 - I_4 - I_5 = 0$$

Kirchhoff's Second Law — the Voltage Law (KVL)

Kirchhoff's Voltage Law or KVL, states that in any closed loop network, the total voltage around the loop is equal

to the sum of all the voltage drops within the same loop. In other words the algebraic sum of all voltages within the loop must be equal to zero (Fig. 1.29). This is called Kirchhoff's Second Law or law of Conservation of Energy.

Starting at any point in the loop continue in the same direction noting the direction of all the voltage drops, either positive or negative, and come back to the same starting point. It is important to maintain the same direction either clockwise or anti-clockwise or the final voltage sum will not be equal to zero. We can use Kirchhoff's voltage law when analysing circuits.

When analysing either DC circuits or AC circuits using Kirchhoff's Circuit Laws. The following terminologies are used to describe the parts of the circuit being analysed, such as

- (a) **Nodes:** when any resistance is connected in the circuit the two terminals of resistance are called nodes.
- (b) **Loop:** when multiple resistances are connected and create a circle, it is called loop.
- (c) **Path:** when multiple resistances are connected with an electrical circuit, the direction of the current flow is called path.
- (d) **Meshes:** hundreds of resistances connected in a circuit in parallel and in series, these are called meshes.

These terms are used in circuit analysis so it is important to understand them.

The sum of all the Voltage Drops around the loop is equal to Zero

$$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$$

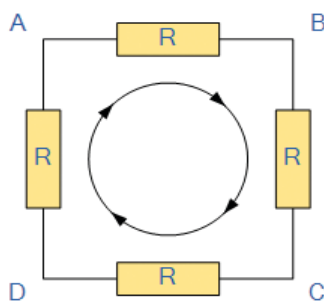


Fig. 1.29 Diagram of Kirchhoff's Second Law



Check Your Progress

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A. Fill in the blanks

1. Light emitted from the surface of conductor is due to _____ of electric current.
2. Magnetic effect of current was discovered by _____.
3. An electric bulb glows when current passes through _____, a conductor.
4. If a changing magnetic field is connected with the coil of a conductor, then _____ is induced in it.

B. Match the columns

1.	Voltage	(a)	Storing Charge
2.	Current	(b)	Obstruction in flow of charge
3.	Resistance	(c)	Flow of charge
4.	Capacitance	(d)	Pressure

C. Multiple choice questions

1. The potential difference between two points is _____.
(a) one volt energy (b) volume
(c) pressure (d) temperature
2. The chemical reaction within a cell generates _____ across the terminals of the cells.
(a) energy (b) potential difference
(c) pressure (d) current
3. Kirchhoff's Current Law states that the algebraic sum of all currents entering and leaving a node must be equal _____.
(a) one (b) two
(c) three (d) zero
4. In any electrical circuit when physical condition (temperature, diameter and length) of a conductor are constant voltage is directly proportional to _____.
(a) current (b) resistance
(c) power (d) energy
5. If two or more resistors (loads) are connected in such a way that they form a chain it is a _____.
(a) parallel circuit (b) series circuit
(c) closed circuit (d) open circuit

D. Short answer questions

1. Explain Ohm's Law in brief with the help of a diagram.
2. Electric current has various effects on chemicals, conductors, the human body, etc. Discuss with suitable examples.
3. An inductor can be defined as an energy storage device. Why?
4. Describe the different parts of a circuit.



SESSION 3: CONCEPT OF ELECTRICAL POWER AND ENERGY

Difference between Power and Energy

Power is the measurement of energy transfer by an electrical circuit in unit time. Electrical power and energy play a vital role in today's society. Electrical power and energy involve generation, transmission and distribution of electrical energy reliably and efficiently to meet consumer demands. Electrical appliances at home like bulbs, heaters, etc., transfer energy from the mains supply to heat and light our homes. Electric energy also operates our appliances, such as TV, microwave and computers, etc. The units measured by an electricity meter and used to calculate the consumption (electricity bill), are kilowatt hours. The cost of each unit of electricity varies. The electricity bill is calculated by multiplying the number of units used by the cost of a unit.

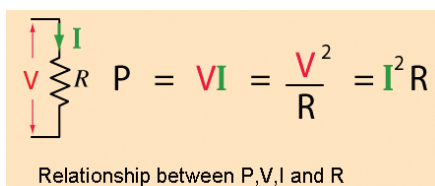


Fig. 1.30 Diagram shows relationship between P, V, I and R

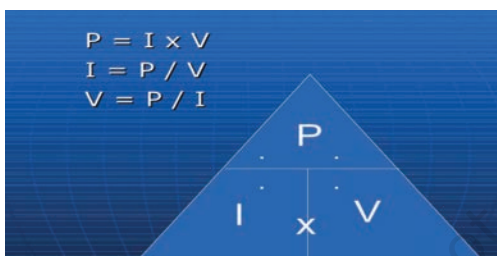


Fig. 1.31 Magic triangle — put your thumb on any one unit and get related Equation

Electrical Power

It is the rate at which electrical energy is consumed by an electrical appliance.

The unit of electrical power is watt.

1000 watt = 1 kilowatt

Electrical Power in DC and AC Circuit

Electrical Power in DC Circuit (Figs. 1.30 and 1.31)

$$P = V \times I$$

$$P = I^2 R$$

$$P = V^2 / R$$

where V=voltage, I=current and R=resistance

Electrical Power in AC Circuit

$$P = VI \cos \phi, \text{ where } \cos \phi = \text{power factor and}$$

P = power

Electrical Energy

Electrical energy is the capacity for doing electrical work.

Energy in watt hour is the multiplication of power in watt and time in hour. This is the basic unit of



energy. The commercial unit of energy is kilowatt-hour (Fig. 1.32).

Electrical Energy = power \times time

Electrical Energy = watt \times hour

Electrical Energy = 1000 watt \times 1 hour

Electrical power in a circuit is the rate at which energy is used or generated within a circuit. A source of energy, such as a battery will deliver power while the connected load uses it. Light bulbs and heaters are examples of usage of electrical power and its conversion into either heat, or light, or both. The higher the value or rating in watts, the more electrical power they are likely to consume. Symbols of electrical circuit are shown in Fig. 1.34.

Electrical power (Fig. 1.33) is also expressed as the rate at which energy is transferred in the circuit. If one joule of work is either absorbed or delivered at a constant rate of one second, then the corresponding power will be one watt. So power can be defined as “1Joule/sec = 1Watt”. Then we can say that one watt is equal to one joule per second and electrical power can be defined as the rate of doing work or the rate of transferring of electrical energy.

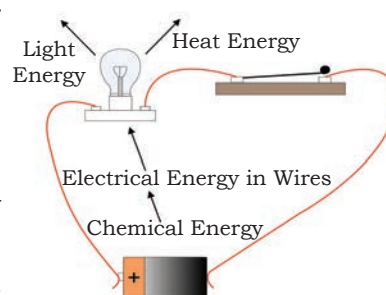


Fig. 1.32 Diagram shows conversion of chemical energy into electrical energy

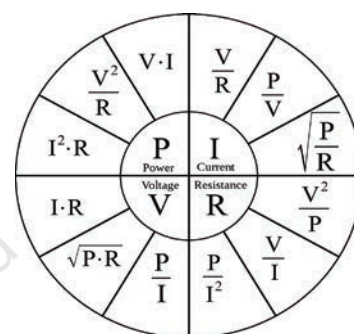


Fig. 1.33 Diagram of electrical power circulation

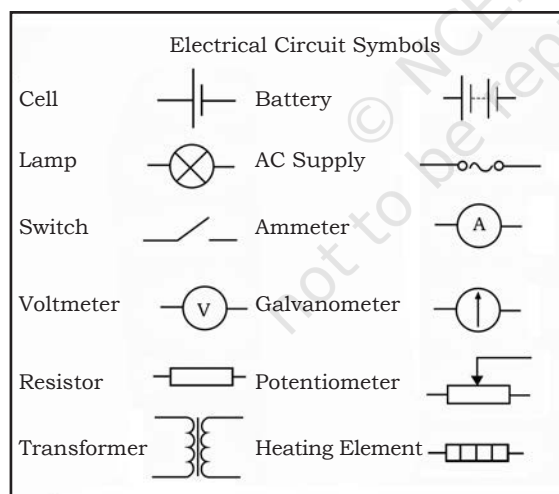


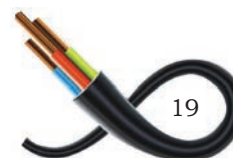
Fig. 1.34 Diagram of electrical circuit symbols

Use of Voltmeters and Ammeters

Voltmeters

1. Voltmeter is always connected across the device or in parallel.
2. Voltmeter has a very high internal resistance, so as not to draw a large current from the circuit.

ELECTRICITY



Ammeters

1. Ammeter is always connected in series.
2. Ammeter has a very low internal resistance, so as not to generate a drop in potential.

Power and Energy Calculation in DC and AC system

(a) Watt: This is a unit of power. It is the rate at which electricity is being used at a specific moment: 1 kilowatt= 1000 watt, 1 Megawatt= 1000,000 watt.

Example 1: 09-watt LED light bulb consumes 09 watts of electricity at any moment when turned on.

(b) Watt-hour: This is a unit of energy. One watt-hour is the energy consumed when one watt of power is

used for one hour: watt-hour = watt × hour. Commercial unit of energy is 1 kilowatt-hour (1 kWh)

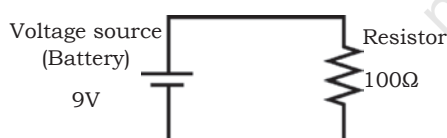
Example 2: 09-watt LED bulb, which draws 09 watts at any one moment, uses 09 watt-hours of electricity in the time of one hour.

Here's the general rule for calculating power dissipation:

Power : $P = V \times I$

where V = voltage, applied across the circuit and I = current flowing in the circuit

Example 3: We begin with one of the simplest circuits: A battery hooked up to a single resistor:



Here, we have a single 9 V battery, and a single 100 Ω (100 Ohm) resistor, hooked up with wires to form a complete circuit. Calculate power and energy in 10 watt-hour.

Calculation of Power: As per formula Power in DC circuit —

Electrical Power = Voltage × Current

$$P = V \times I$$

As per Ohm's Law $V=IR$ (where R = resistance of the circuit)

$$I = V/R$$

Then, $P=V \times V/R$

$$P = V^2/R$$

$$P=9^2/100=81/100=0.81 \text{ watt}$$



Solution: Power dissipated in the electrical circuit is 0.81 Watt

Calculation of electrical energy: As per the formula of electrical energy in DC circuit —

Electrical energy = Power (in watt) × Time (in hour)

Then, electrical energy consumed for 10 hours = $0.81 \times 10 = 8.1$ watt-hours

Solution: Energy consumed by above electrical circuit is 8.1 unit.

Question: Calculate the electrical power and energy consumed in 5 hour of the electrical DC given circuit (Fig. B).

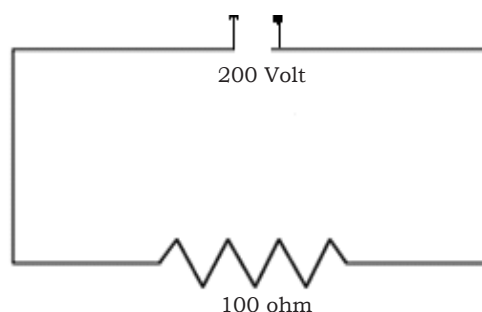


Fig. B

Check Your Progress

A. Fill in the blanks

1. Electrical power involves _____, _____, and _____ of electrical energy.
2. _____ is the rate at which electricity is used at a specific moment.
3. A _____ is always connected across the device or in parallel.
4. The commercial unit of electricity is known as _____.
5. Ammeter has a low internal resistance so as to not generate a _____ in potential.

B. Match the column

1. Battery	(a)	Current indicating device
2. Galvanometer	(b)	Resists the flow of a current
3. Resistor	(c)	A resistance which generates heat
4. Heating Element	(d)	Combination of two or more cells

C. Multiple choice questions

1. AC stands for _____.
 - (a) alternating current
 - (b) direct current
 - (c) power
 - (d) energy
2. The internal resistance of an ammeter is _____.
 - (a) high
 - (b) low
 - (c) zero
 - (d) infinite
3. What is required to produce electric current?
 - (a) Voltage
 - (b) Source of energy
 - (c) Electric field
 - (d) All of these



NOTES

4. Potentiometer is an electric device that gives variable _____.

- | | |
|-------------|----------------|
| (a) power | (b) resistance |
| (c) voltage | (d) current |

D. Short answer questions

1. What is one commercial unit of electrical energy? Explain briefly.
2. An electric iron is connected across 220 volt power supply. If the resistance of the iron is 50 ohm, then calculate
 - (a) the current flowing through the iron.
 - (b) electrical power of the iron
 - (c) energy used in commercial units (kWh) if the iron is connected for 2 hours.
3. One LED bulb is labeled '220 volt and 11 watt'. If the bulb is connected to 220 volt power supply, then calculate
 - (a) the current that flows through LED bulb.
 - (b) the amount of electrical energy used by the LED bulb in 8 hours.

E. Draw the electrical symbols of the following

1. Cell
2. Battery
3. Bulb
4. Resistance
5. Switch

SESSION 4: IMPORTANCE OF EARTHING SYSTEM

Earthing is set up in an electrical circuit to ensure safety. This system provides an alternative path for high and dangerous current to flow to the earth so that the problem of electric shock and damaging of equipment does not occur.

The metallic connection between electrical machines and devices with the earth plate, commonly known as earth electrode, through a thick wire of low resistance to provide safety is known as earthing.

Metallic parts of all equipment are earthed and if the equipments' insulation fails there can be dangerous current present on the surface of the equipment. This may cause a short-circuit and the fuse will blow off immediately.



Earthing

Earthing means connection of non-current carrying parts (metallic parts) of electrical apparatus to the earth to discharge electrical energy without any danger.

Earthing is done by connecting the appliance or machinery to earth by good conductor known as earth electrode. Earthing is done to save human life from the danger of electrical shock, in case human body comes in contact with live wire of electricity (Fig. 1.35).

If earthing is done correctly and the metallic part comes in contact with live wire, it will be discharged into the earth. In this condition due to zero potential of earth a large amount of current flows to the earth. If the current exceeds the limiting value of the fuse, it blows off or MCB trips and cuts off the appliance from supply.

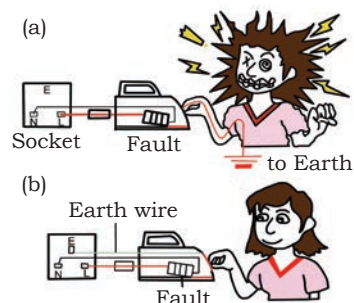


Fig. 1.35 Proper Earthing

Specifications for Earthing

S.No.	Details	Specification
1.	Distance of earth from building	More than 1.5 meter from the building
2.	Size of earth electrode	Not be less than 2.9mm^2 or 14 SWG
3.	Resistance of earth	Not greater than 8 ohm

The earth electrode and earth wire will be of the same material.

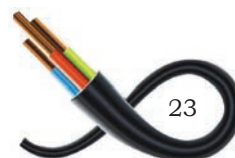
Points to be earthed

1. Earth pin of 3 pin and 5 pin plug and socket.
2. All metal parts of electrical machine, e.g., motor, heater, geyser and mixer.
3. Metallic frame of electrical machines.
4. The neutral conductor of 3-phase 4-wire system.
5. Pole, tower, armouring of cable.
6. Stray wire of overhead lines.

Importance of Electrical Earthing

Electrical earthing is important to

1. save human life from the danger of shock from leakage current.



NOTES

2. maintain the line voltage constant.
3. protect large machine and building from atmospheric lighting.
4. avoid the risk of accident in electrical substation and other installation.

Earth resistance of different electrical installation

Large Power Station	0.5 Ohm
Major Power Station	1.0 Ohm
Small Sub-Station	2.0 Ohm
In house wiring and such other case	5.0 to 8.0 Ohm

Types of Earthing

- 1. Strip earthing:** In this type of earthing galvanised iron strip of 25mm × 4mm or copper strip of 25mm × 1.6mm are laid in horizontal trenches of minimum depth of 0.5 meter and covered with charcoal and salt.
- 2. Rod earthing:** In this type of earthing system 12.5 mm diameter of solid rod of copper or 16 mm diameter of solid rod of galvanised iron are fitted vertically into the earth not less than 2.5 meter on the earth's surface.
- 3. Pipe earthing:** Pipe earthing is cheaper and the best form of earthing. In this type of earthing a hollow pipe of 38 mm diameter and 2.5 meter long GI is placed underground of the earth and covered with charcoal and salt.
- 4. Plate earthing:** In this type of earthing system, a plate of either copper with dimensions 60cm × 60cm × 3.18mm or galvanised iron (GI) of dimensions 60cm × 60cm × 6.35 mm is buried vertical in the earth pit which should not be less than 3 meter from the surface of ground.

The most commonly used types of earthing are

(a) Pipe Earthing

This type of earthing is used widely in industries and house wiring system. In this system of earthing a GI pipe of 30 mm diameter and 2.5 m length is buried vertically



in ground to work as earth electrode. The depth depends upon the soil conditions; there is no hard and fast rule for this. The earth electrodes are connected to the top section of the pipe with nut and bolt. The pit area around the GI pipe is filled with alternate layer of salt and charcoal for reducing earth resistance. It can take heavy leakage current for the same electrode size in comparison to plate earthing. Water is filled through a pipe to maintain the resistance of earth electrode. Pipe earthing (Fig. 1.36) is the best form of earthing and it is also a cheap method of earthing.

Earthing pipes are also known as earthing electrode pipes, these can be used in houses, offices as well as in power stations. Earthing pipes are used in electrical installation, transmission line and other installation. Copper pipe is generally used in earthing system.

The pipe size depends upon the current to be carried and on the soil type. Pipe earthing is reliable, durable, easy to handle and highly secure. Connectivity of the pipe earthing is up to the chamber or earth terminal. The connection of earth wire from machine to galvanised iron pipe, being above the ground level makes it easy to check for any discontinuity. To have an effective earthing in summer season, pipe earthing gives us the freedom to put 2–3 buckets of water through the funnel, which helps in achieving effective earthing. This is one of the most widely used methods of earthing.

(b) Plate Earthing

In this type of earthing, a plate of copper or GI is buried into the ground at a depth of greater than 3 m.

Earthing plate is filled with alternate layers of salt and coke not less than 46 cm (1.5 feet) so to provide lesser resistance due to absorption of moisture. The earth conductor is properly bolted to an earth plate with the help of nut and bolt and washer made of copper, in case of copper plate earthing and of GI in case of GI plate earthing (Fig. 1.37).

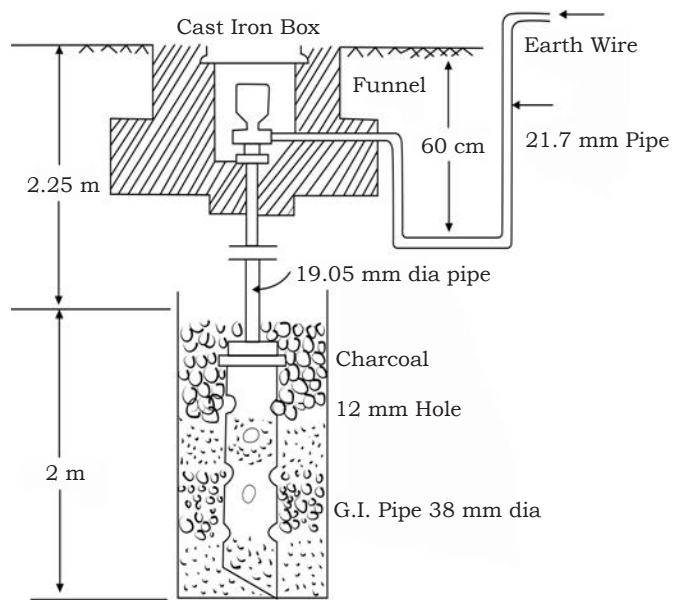


Fig. 1.36 Pipe earthing



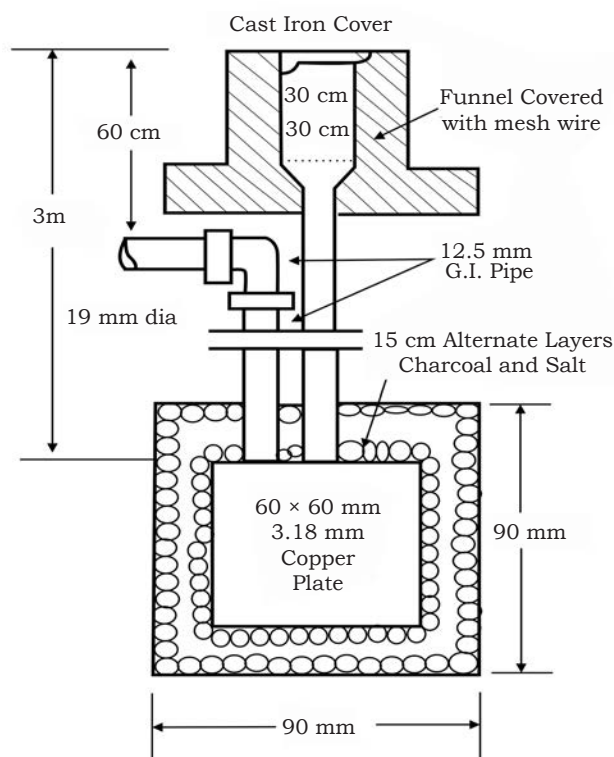


Fig. 1.37 Plate earthing

1. For GI earthing plate size should be – 600 mm × 600 mm × 8.30 mm
 2. For copper earthing plate size should be – 600 mm × 600 mm × 3.15 mm
- Pit size made for maintenance should be 30 cm × 30 cm. so as to provide ease of accessibility of maintenance of these earthing pits and for testing of earthing pits.

Advantages of Earthing

One of the major objectives of earthing is to ensure safety of persons during leakage fault conditions. Earthing creates the path of least resistance from machine to the earth so that the fault current dissipates quickly. It allows the electrical energy to be safely dissipated thereby minimising the danger caused by leakage. Earthing is the key to

safety i.e., protection of personnel, equipment, wiring, machines and instruments. Another advantage of earthing in the context of communication tower is to reduce electromagnetic interference.

Both plate or pipe earthing can be used. However, plate earthing is preferred in small buildings and pipe earthing is preferred for multistorey buildings as well as electrical substations. All metallic parts of electric machines must be earthed for safety of the equipment.

Atmospheric Lightning

Atmospheric lightning is a form of visible discharge of electricity between a rain cloud and the earth. The electric discharge is seen in the form of an arc between the cloud and the earth's surface.

When the electrical potential between two clouds, or a cloud and the earth reaches a sufficiently high value the air becomes ionised along a narrow path and results in a flash of lightning.



The possibility of lightning is more on tall trees and buildings rather than on the ground. Buildings are protected from lightning by metallic lightning rods. These lightning rods are known as lightning arresters. This lightning arrester is fitted at the highest part of the roof and it is extended to the ground through a conductor. The conductor has a pointed edge on one side and the other side is connected to a long thick copper strip which runs down the building. The lower end of the strip is properly connected to the earth. When lightning strikes on the rod, current flows down through the copper strip. These rods provide a low-resistance path for the lightning discharge and prevent it from travelling through the structure of the building itself.

Lightning Arrester

The principle of the lightning arrester was first discovered by Benjamin Franklin in 1749, who in the subsequent years developed his invention for household application.

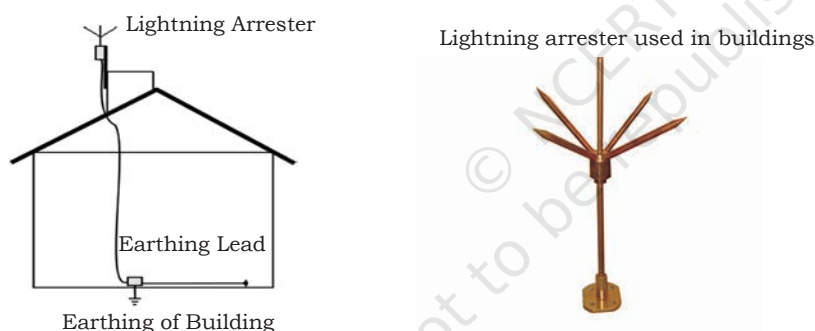


Fig. 1.38 Lightning arresters

Lightning arresters (Fig.1.38) are devices which prevent damage of apparatus due to high lightning voltages. The lightning arrester provides a low resistance path to ground for the current from a lightning strike.

When a high voltage or a voltage greater than the normal line exists in the circuit, the lightning arrester immediately provides a path to the earth and thus limits and drains off the excess voltage.

Working of Lightning Arrester

1. A lightning arrester does not absorb any charge caused by lightning.



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2. A lightning arrester diverts the charge towards the ground.
3. A lightning arrester limits the voltage produced by atmospheric lightning.
4. A lightning arrester will work at the time of lightning because it produces very high voltages.
5. A lightning arrester provides protection against lightning surges during the rainy season.

Earth Resistance

1. Earth resistance depends on following factors
 - (a) Type of earth soil
 - (b) Temperature of earth
 - (c) Humidity in earth
 - (d) Minerals in earth
 - (e) Length of electrode in the earth
 - (f) Electrode shape and size
 - (g) Distance between two electrodes
 - (h) Number of electrodes
2. Maximum earth resistance allowed is as follows:
 - (a) Major power station — 0.5 ohms
 - (b) Major Sub-stations — 1.0 ohms
 - (c) Minor Sub-station — 2 ohms
 - (d) Neutral Bushing — 2 ohms
 - (e) Service connection — 4 ohms
 - (f) L.T Lightning Arrestor — 4 ohms
 - (g) L.T. Pole — 5 ohms
 - (h) H.T. Pole — 10 ohms
 - (i) Tower — 20-30 ohms

Earth Tester and Earth Resistance

Earth tester is used to measure earth's resistance. If earth resistance is high, certain processes need to be adopted.

Working of Earth Tester

Earth tester consists of hand operated D.C. generator, 4 spikes and connecting wire. These spikes are



connected through wire to terminals of earth tester. Spikes are inserted in the ground to check the earth resistance. Current is fed to the spikes through DC generator. DC current is converted into AC current by the converter and AC current received from spike is again converted in DC current with the help of a rectifier. While going to generator, AC current is fed to the spike driven in earth because there should not be electrolytic effect.

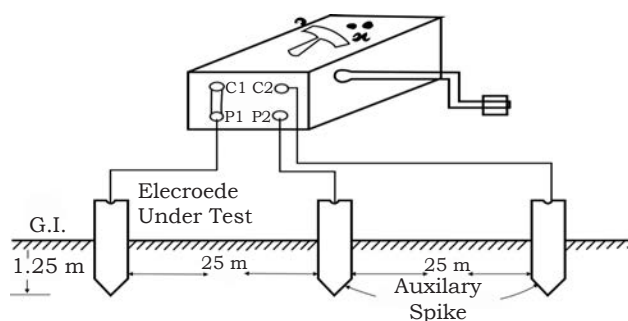


Fig. 1.39 Measurement of Earthing Resistance—Three-Point Method

Three-point Method

In this method, earth tester terminals C1 and P1 are shorted (joined) to each other and connected to the earth electrode (pipe) under test. Terminals P2 and C2 are connected to the two separate spikes driven in earth. These two spikes are kept in the same line at a distance of 25 meters and 50 meters due to which, there will not be mutual interference in the field of individual spikes. If we rotate the generator handle with specific speed, we get the earth's resistance directly on scale. This method of testing is known as three point method (Fig. 1.39).

Note: Spike length in the earth should not be more than $1/20$ th distance between two spikes.

Four-point Method

In this method, four spikes are driven in earth in same line at the equal distance. Outer two spikes are connected to C1 and C2 terminals of earth tester. Similarly inner two spikes are connected to P1 and P2 terminals. Now if we rotate generator handle with specific speed, we get earth's resistance value of that place.

In this method error due to polarisation effect is eliminated and earth tester can be operated directly on AC.

If earth's resistance is higher than done the above values, following treatments can be to minimise resistance:

- (a) Oxidation on joints should be removed and joints be tightened.



NOTES

- (b) Sufficient water should be poured in earth electrode.
- (c) Earth electrode of bigger size as far as possible should be used.
- (d) Electrodes should be connected in parallel.
- (e) Earth pit of more depth and width-breadth be made.

Check Your Progress

A. Fill in the blanks

1. The metallic connection between electrical machines and devices with earth plate is known as _____.
2. Absence of earthing causes _____.
3. The resistance between earth electrode and earth in ohms is called _____.
4. Lightning arrester prevents damage of _____.

B. Match the columns

1.	Large Power Station	(a)	5.0 to 8.0 ohm
2.	Major Power Station	(b)	5 ohm
3.	Small Sub-Station	(c)	2 ohm
4.	In House wiring and such other case	(d)	1 ohm

C. Multiple choice questions

1. Maximum earth resistance value of major power station is _____.
 - (a) 0.5 ohm
 - (b) 2 ohm
 - (c) 1 ohm
 - (d) 8 ohm
2. One of the most common type of earthing is _____.
 - (a) plate earthing
 - (b) pipe earthing
 - (c) rod earthing
 - (d) strip earthing
3. Earthing pipes are not used for _____.
 - (a) electrical installation
 - (b) transmission line
 - (c) industry
 - (d) atmospheric light



NOTES

4. For maintaining moisture around the earthing we use _____.
 - (a) salt and charcoal
 - (b) sugar
 - (c) oil
 - (d) none of them
5. Every metallic electrical pole must be _____.
 - (a) grounded
 - (b) earthed
 - (c) phase
 - (d) neutral

D. Short answer questions

1. Explain the process of pipe earthing.
2. The high resistance of earth needs to be controlled for certain processes. Analyse the importance of earth tester in this context.
3. Draw a simple diagram of plate earthing.
4. Discuss the factors which affect earth's resistance.

